Small benthic Crustacea of the Leschenault Inlet estuary

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Abstract

Twenty-one species of small benthic and epibenthic crustaceans were recorded for the Leschenault Inlet estuary over the period 1982-1997. Two are new species, and eight species are probably new records for Western Australia. The most abundant species were *Tanais* sp nov and *Corophium* sp. Small benthic crustaceans had both widespread and restricted distribution patterns within the estuary. Spatial distributions of species appear to be linked to salinity patterns or to the presence of aquatic vegetation, and a few species also showed preference for particular substrates or depths. Summer and winter distributions varied. Changes in population density and distribution were likely linked to adult migration and juvenile recruitment. Over the five-year monitoring period, small benthic crustacean populations typically showed a seasonal unimodal peak in numbers during summer. This juvenile recruitment resulted in summer population densities typically an order of magnitude greater than winter densities. Less common species showed monthly to seasonal patterns that are difficult to interpret due to their sporadic occurrence in samples. The summer recruitment magnitude for most species varied annually, thus recruitment appears to be linked to favourable environmental conditions. A long-term environmental change within the Leschenault Inlet estuary was documented over this five-year period through the overall decline in abundance of the main species and through changes in species composition.

Keywords: benthic crusteans, Leschenault Inlet, estuary, south-western Australia.

Introduction

There have been few previous studies of small benthic crustaceans from Leschenault Inlet estuary or other estuaries of south-western Australia. Chalmer & Scott (1984) documented a number of small crustaceans as part of their fish and benthic fauna survey of the Leschenault Inlet estuary. In their study, the Leschenault Inlet estuary was sampled on a single occasion at three main localities: the inlet, central basin and northern flat of the estuary. They recorded three genera of amphipod, one species of isopod, and five decapods (mostly shrimps). Deeley (*pers. comm.* 1999 School of Environmental Science, Murdoch University) recorded small crustaceans from benthic samples collected along a north-south transect of Leschenault Inlet estuary, noting four amphipod taxa although only one was identified to species level. Hodgkin & Clark (1987-1990) compiled inventories of small benthic crustaceans from south-western Australian estuaries and coastal lagoons, listing a total of three amphipods, one talitrid (unidentified), one isopod and six decapods (mostly shrimps). Some records of small benthic crustaceans also were available from the crustacean database of the Western Australian Museum of Natural Science. These studies provide only an indication of species found in south-western Australian estuaries on single sampling surveys, without replication in time or in space. In this paper, I provide an inventory of species compiled from data collected seasonally over five years at 22 sites within the estuary, and address spatial and temporal changes in abundance and composition of key species over this time.

Methods

Regional setting

Leschenault Inlet estuary is a north-south elongate basin with rivers located at its southern end. The marine access channel also is located at the southern end through an artificial cut (V Semeniuk, 2000). The position of the mouth and head of this estuarine system generates a non-linear gradation in salinity and substrate types from lower to upper reaches. Although the range of salinity within the basin is within estuarine conditions, the variability of salinity in different sections is atypical in comparison with classic estuaries described by Day (1981).

The Leschenault Inlet estuary was subdivided into habitat and hydrochemical sectors by Wurm & Semeniuk (2000). Four divisions are recognised on the basis of salinity; upper, mid, lower-estuarine and deltaic regions. This subdivision provides a framework within which to interpret distribution patterns of benthic fauna. Wurm & Semeniuk (2000) and Semeniuk (2000) describe physical, chemical and sedimentological aspects of Leschenault Inlet estuary in some detail. Descriptions of salinity, substrate type, and aquatic vegetation are only briefly reiterated here to provide a context for the sampling sites (Fig 1). Salinity regimes are described after the Venice system for brackish waters (Anon, 1959).

Sampling of benthic fauna was undertaken along four cross-inlet transects, noted A-D (Fig 1). Biomass samples of the seagrass *Halophila ovalis* and algae were collected in 1986. Records of vegetation recorded along transects is provided below. Transect A (sites A1-7) is located mostly within the deltaic salinity field; water is typically

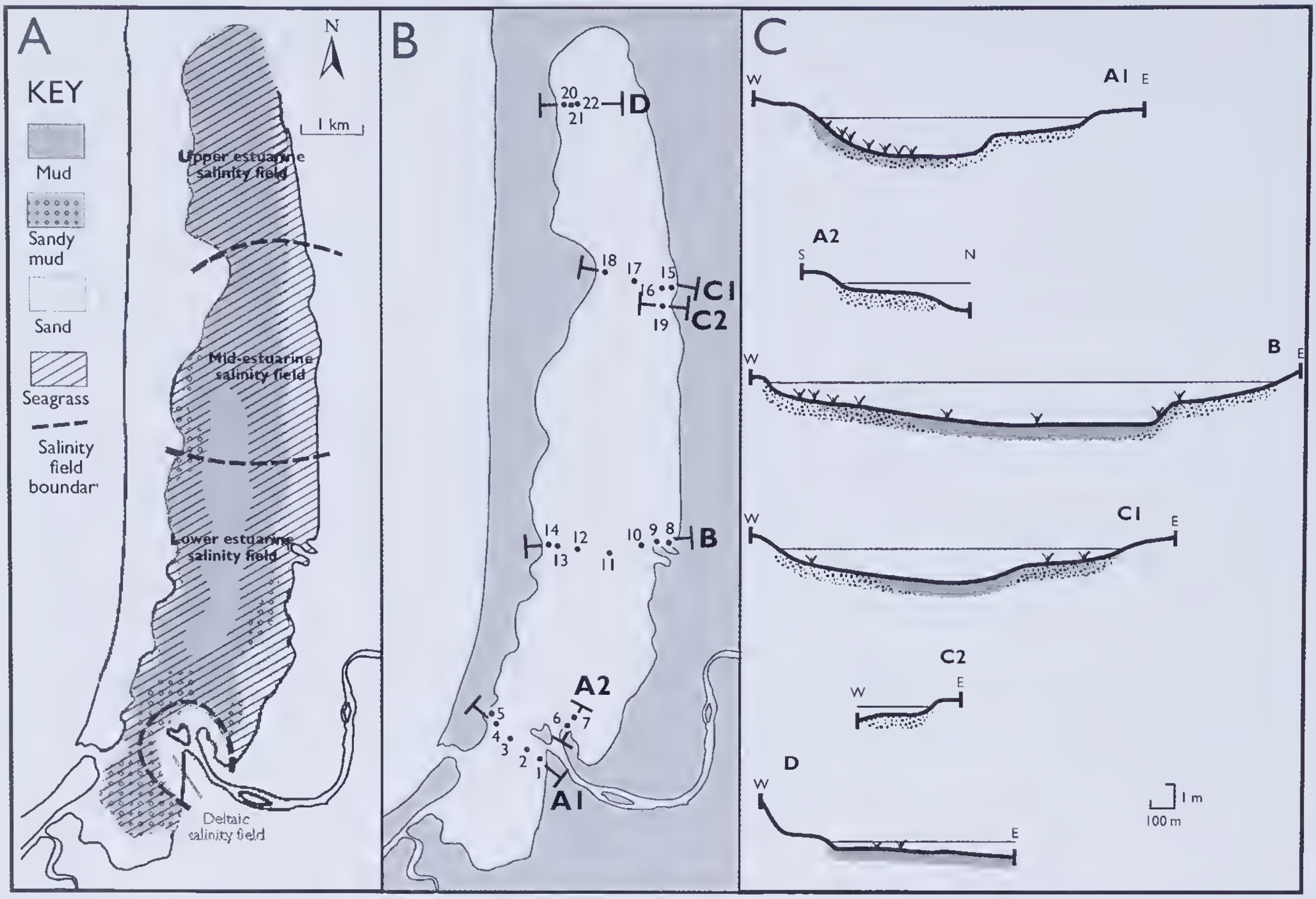

Figure 1. A: Habitat framework for Leschenault Inlet after Wurm (1987) showing salinity fields and main substrate types with superimposed distribution of seagrass species *Halophila ovalis* after Lukatelich (1993). B: Sampling sites. C: Detail of habitats along the four east-west transects after Wurm (1987). Seagrass records are from 1986 sampling trips and are marked at sampling sites only.

mesohaline in winter at sites A1-2 and A6-7, euhaline in winter at sites A3-5 and euhaline in summer at all sites (salinity range per annum is typically 15-40 ‰). Substrates are generally sandy with sandy mud in the central zone of the estuary, corresponding to the deeper basin area (sites A4 and A5). Sites A3-5 had *Halophila* present (sites A1-2 and A6-7 are located on the delta front and had no seagrass present). Algae were present at sites A5-7. Transect B (sites B8-14) is located in the lower-estuarine salinity field; water is euhaline throughout the year (salinity range per annum is 35-40 ‰). Substrates grade from sand on the eastern margin to mud in the deeper basin region (sites B11 and B12), and to sandy mud on the western margin. *Halophila* was present at all sites. Algae occurred only on the western margin at sites B13 and B14. Transect C (sites C15-19) is located in the mid-estuarine salinity field; water is euhaline throughout the year, but fluctuates within this category at shallow-water sites C15-16 and C18-19 (salinity range per annum is 30-45 ‰). Substrates grade from sandy mud on the eastern margin to mud in the deeper basin region and western margin. Both *Halophila* and algae occurred along the shore margins at sites C15, C16, and C18. Transect D (sites D20-22) is located in the upper-estuarine salinity field; water is hyperhaline in summer and polyhaline in winter (salinity range per annum is 25-60 ‰). Sites are located in the intertidal zone and hence experience a more extreme seasonal temperature range than other sites in the estuary. Temperature range is 15-30 °C per annum. Substrates are typically muddy with patchy algal cover.

Methods

Small benthic and epibenthic crustaceans were collected on surveys of Leschenault Inlet estuary between February 1982 and May 1987. Fauna samples were first collected on a reconnaissance survey in February 1982, when ten replicate samples at a total of 26 sites were collected. Sampling was continued seasonally along the four transects described above between May 1982 and May 1987. On these later surveys, five replicates at each of the 22 sites were collected.

In addition, five samples were collected monthly at eleven of the above sites (sites A2, A3, A4, B9, B11/12, C15, C17, C19, D20, D21 and D22) from June 1986 to May 1987 to provide more detailed information on population dynamics of fauna species along these transects. A total of 3025 samples were collected. Samples were collected in August 1997 at each of the sites A4, C15 and D22 to provide additional specimens for taxonomy.

The scope of spatial and temporal replication in samples throughout the estuary provides an important benthic data-base for estuarine environments. These samples are used to determine species distribution within the estuary and to assess the significance of habitat associations within the framework described by Wurm & Semeniuk (2000). The time scale over which the samples were collected gives an indication of species response to the fluctuating physical and chemical conditions in this estuary. Abundance and species composition are analysed on a seasonal to annual basis, and also over the five-year period.

The sampling method used in this study was designed specifically for smaller benthos. However, epiphytic and nektonic species were commonly recorded at vegetated sites because animals were trapped in collected vegetation.

Benthos was collected by randomly taking cores, 10-cm diameter and 15-cm deep, from the sediment surface. Thus, a 78.5 cm^2 surface area was excavated to 15 cm depth. This ensured 95% probability of collecting organisms with living densities greater than 0.06 specimens dm^{-3} (Dennison & Hay 1967). Spatial replication meant that a total of *ca* 400 cm^2 was investigated at each site on each sampling trip. This ensured 95% confidence of collecting species with densities as small as 0.009 specimens dm^3 (Dennison & Hay 1967). Abundance of individual species is given in this paper as specimens per sample for the purpose of comparison of fauna densities between sites and species. This avoids errors induced by assuming constant density or no small-scale heterogeneity when extrapolating to larger areas. Specimens per sample can be converted to specimens per m^{-2} by multiplying by a factor of 127.

Sediment and any surface vegetation was removed and washed over a 1 mm sieve in the field. Fragments of menthol were added to samples containing polychaetes immediately after collection, as part of the collecting procedure for associated polychaetes. Initially, sieved residue was decanted into bottles, fixed in formaldehyde, rewashed and then stored in 10% phenoxytol solution. Benthos was picked from the residue in a laboratory at a later date. Specimens were analysed in 1996-1997. Samples were collected in 1997 to provide fresh material for taxonomic work.

Taxonomic reference standards were established using the expertise of J Lowry and B Wilson at the Western Australian Museum, and the following literature: Hale (1927-1929), Barnard (1969, 1972), Barnard & Karaman (1991), and Poore & Lowry (1997). Specimens were sorted and counted from each sample. A total species list was compiled from these data for the Leschenault Inlet estuary. Additional records from 1997 were added to the list.

The nature and scope of the Leschenault Inlet estuary environmental surveys emphasised the collection of information on habitats, sedimentology, molluscan fauna, and general other benthic fauna. There was no specific focus on collecting and preserving small benthic crustaceans. In contrast to the preservation methods outlined above, ideally, samples for small benthic crustaceans should have been sieved over a mesh finer than 1 mm, and specimens picked in the field. Also, ethanol would have been a better storage medium, since failure to remove all formaldehyde and menthol contributed to deterioration of some material in a small number of samples (Gatanby & Beams 1950). However, comparison of reference standards with older material enabled identification of most specimens in these instances.

To evaluate distribution of species within the Leschenault Inlet estuary and to assess habitat associations, species are classified as very common (>20 specimens per sample), common (5-20 specimens per sample) and uncommon (0-5 specimens per sample) based on modal data from the sampled sites. Species distribution maps are provided for the most common small benthic crustacean species within the Leschenault Inlet estuary.

Sites representing shallow-water sand and mud, and deep-water mud habitats are considered in detail. These sites are selected to show the transition from lower to mid-estuarine salinity fields in the central basin muds (A3, B12 and C17) and shallow-platform sands of the western margin (B9 and C15). The northern flat site, D22, represents the shallow-water muds of the upper salinity field.

Results

Species inventory

A total of 21 benthic and epibenthic species of small crustaceans were recorded for the Leschenault Inlet estuary in this study (Table 1). Fifteen species were recorded over the period 1982-1987, with an additional six species recorded from 1997 samples. Eight species probably represent new records for Western Australia, based on a search of the Western Australian Museum of Natural Science records; however, two taxa are new species; *Tanais* sp nov and *Grandidierella* sp nov (J Lowry, Western Australian Museum, *pers. comm.*). *Paranthura* sp may also be a new species, since no similar specimens of this family are lodged at the WA Museum.

Table 1. Species list of small benthic crustaceans for Leschenault Inlet

Species	Life mode
AMPHIPODA	
Austrochiltonia subtenuis	epibenthic
Amphitoe cf kulafi ledoyer	epibenthic
Amphitoe ugana	epibenthic
Amphitoe cf valida	epibenthic
Amphitoe sp	epibenthic
Caprella cf penantis	epibenthic - nektonic
Corophium sp	benthic
Ericthonius pugnax	benthic
Grandidierella sp nov	epibenthic
Grandidierella japonica	epibenthic
Melita zylandica kauerti	epibenthic
Melita matilda	epibenthic
Melita sp	epibenthic
Paracorophium excavatum	benthic
Tethygeneia elanora	epibenthic
ISOPODA	
Tanais sp nov	benthic
Sphaeroma quoyanum	benthic
Paranthura sp	benthic
DECAPODA	
Ebalia intermedia	benthic
Halicarcinus ovatus	benthic
Illyoplax sp	benthic

The most abundant small benthic species were *Corophium* sp, and *Tanais* sp nov. Specimens of *Caprella cf penantis*, *Paranthura* sp, *Melita zeylandica kauerti* and *Melita matilda* also were regularly recorded in the samples. Other species were recorded only rarely, or only in 1997. Only species with average specimen totals greater than one per sample will be discussed further. These are *Corophium* sp, *Tanais* sp nov, *C. cf penantis*, *Paranthura* sp, and *Melita zeylandica kauerti*.

Diversity

Overall species diversity for this estuary was low. Samples typically contained between 1-3 species. Highest diversity was recorded along Transect A: basinal sandy mud site A3 and platform muddy sand site A4 typically had eight species present. Diversity decreased slightly from Transect B in the lower-estuarine region to Transect C in the mid-estuarine region, from around six to four species per site, and then increased to seven species per site along the upper-estuarine Transect D.

Highest diversity thus occurred in the regions with close to normal marine salinities and stable temperatures. High diversity also occurred in the regions of greatest salinity and temperature fluctuation *i.e.* the upper-estuarine reach and the deltaic region. Lowest diversity correlated with the mid-estuarine field, which had higher than normal marine salinities and relatively stable temperatures.

Spatial patterns

Distributions of small benthic crustacean species within the estuary were either widespread or restricted (Fig 2). Abundance data for individual species for each site are presented in Table 2. Density patterns within the estuary are described below for each of the key species.

Tanais sp nov was widespread within the Leschenault Inlet estuary. It was recorded at all 11 sites that were monitored monthly. High numbers of specimens were recorded at most shallow-water sites; B8-9, C15-16, C18-19, and D21-22. The species was more abundant at shallow-water sites on the eastern and northern margin, where there were population densities of up to 150 specimens per sample in summer.

Corophium sp also was widespread within the Leschenault Inlet. It was recorded at all of the 11 sites monitored monthly, occurring with highest frequency in the Collie Delta region at site A2. High frequencies also were recorded at lower-estuarine basin site A3 and mid-and lower estuarine shallow sandy sites B9 and C15 along the eastern estuary margin. At these sites population densities were up to 100 specimens per sample in summer. *Corophium* sp was recorded in much lower numbers along Transect D, where sample densities were typically 1-2 specimens per sample. This species had a widespread distribution within Leschenault Inlet estuary.

Paranthura sp similarly was widespread, and recorded at all 11 sites that were monitored monthly. However, it occurred most commonly within the mid-estuarine salinity field. Summer distributions typically extended into both the upper and lower estuarine salinity fields. Highest densities were recorded at basin and platform sites with muddy substrates; densities were up to 13 specimens per sample in summer. The distribution pattern within Leschenault Inlet estuary was restricted.

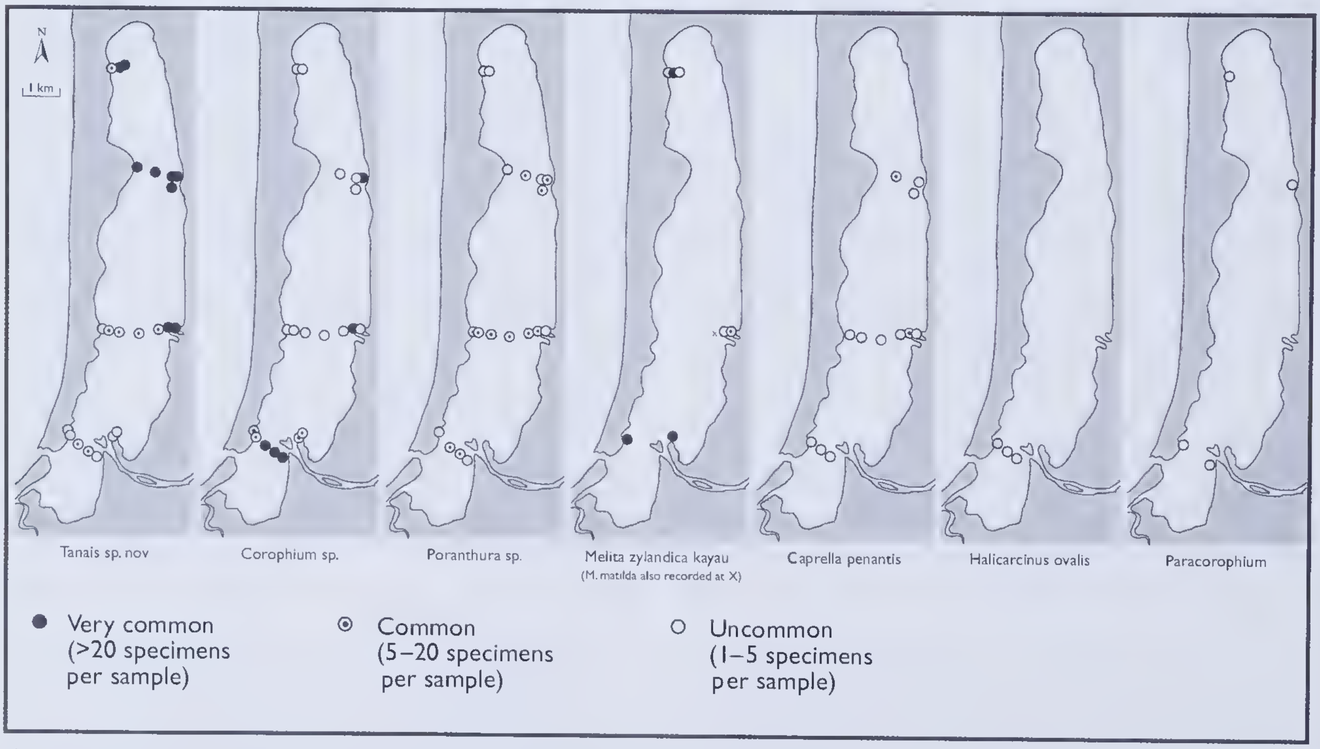

Figure 2. Species abundance at monitored sites based on maximum abundance recorded between 1982-87. This gives an indication of net distribution within the estuary, but does not represent occurrence at a given time, since abundance varied seasonally and annually at sites.

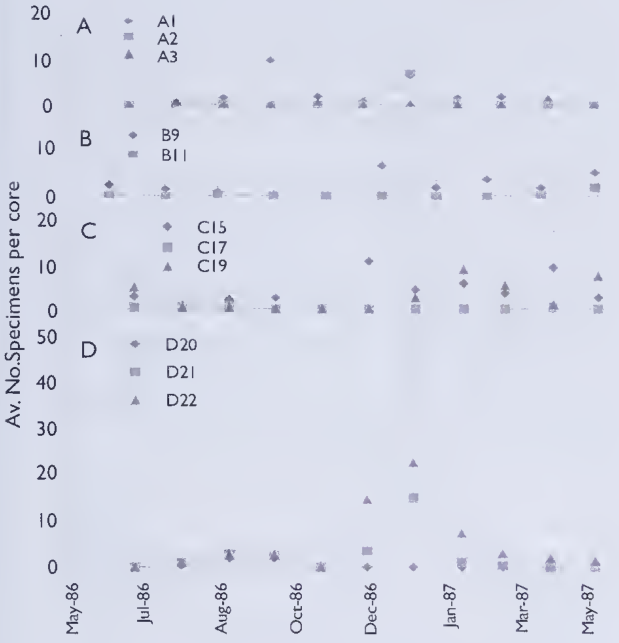

Figure 3. Monthly change in mean abundance of *Tanais* sp nov at monitored sites along the four Transects (A-D) over the period May 1986 to May 1987 (mean and standard deviation is calculated from five sample replicates collected each month at each site).

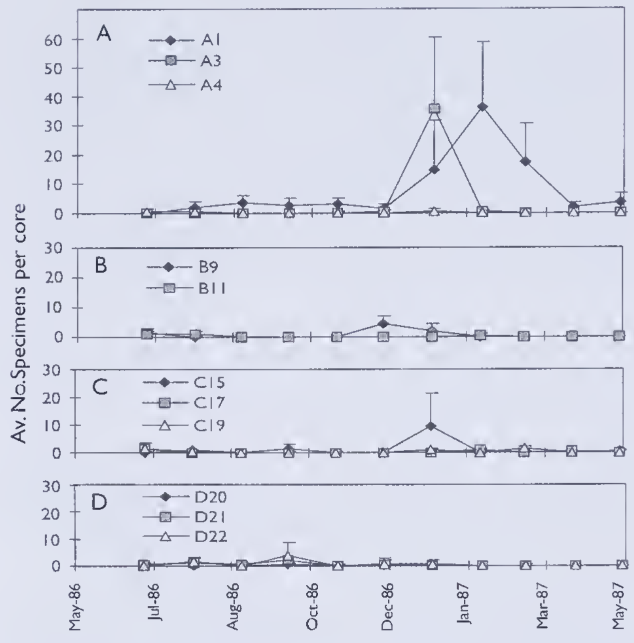

Figure 4. Monthly change in abundance of *Corophium* sp at monitored sites along the four Transects (A-D) over the period May 1986 to May 1987 (mean abundance and standard deviation calculated from five sample replicates collected each month at each site).

Caprellid shrimps and most amphipods were recorded mainly from vegetated sites. *C. cf penantis* was generally recorded from seagrass substrates along Transects A-C (within the lower to mid-estuarine salinity fields) at sites A3, A5, B9, B10-11, and C16-17 of the sites monitored monthly. It was recorded most frequently and with highest numbers at sites A3, B9-10 which correlates with high density of aquatic vegetation. It typically occurred at densities of 1-7 specimens per sample. Summer and winter distributions of *C. cf penantis* varied slightly: the summer distribution was more widespread within the estuary and it was recorded more frequently along Transect A. There were few records of this species from Transect D. This species was confined to regions with close to normal marine salinities within the estuary.

Melita spp were recorded from nearshore sites along Transects A, B and D. *M. zeylandica kauerti* was most frequently recorded. Summer and winter distributions of *M. zeylandica kauerti* varied slightly: it was recorded year-round at Collie Delta and northern flat sites, but was only recorded at mid-estuarine nearshore sandy sites B8-10 in summer. *M. zeylandica kauerti* occurred at densities of up to 3 specimens per sample. *M. matilda* was recorded only during summer in 1984 and 1986 from sites A4, A7, B8, B10, and D21. Both species of *Melita* had restricted distribution patterns within Leschenault Inlet estuary.

Small crabs, especially *Halicarcinus ovatus,* were recorded along Transect A at sites A2-4. These sites are located in the lower-estuarine salinity field, in muddy sands from deeper water regions of the central basin. Small crabs were recorded rarely; their distribution patterns were very restricted within Leschenault Inlet estuary.

Other crabs (*e.g. Ebalia* and *Illyoplax*) and most amphipods (*e.g. Amphitoe, Grandidierella, Ericthonius, Tethygeneia*) were too rare to establish distribution patterns. However, amphipods from the genera *Amphitoe* and *Grandidierella* were typically recorded in algae-rich samples.

Temporal patterns of species

Analysis of the 1986/87 data collected at monthly intervals indicates that the three most abundant species typically recruited in summer (Figs 3-5). Monthly to seasonal changes in abundance of less common species is difficult to interpret due to their sporadic occurrence in samples.

The number of specimens of *Tanais* sp nov increased in summer at most of the sites that were monitored, with the exception of deeper water basin sites A4, B11, C17 and intertidal site D20 where numbers remained steadily low (Fig 3). The highest average number of specimens was recorded at sites D21 and D22, where numbers changed from an average of 0-2 specimens per sample up to 30 specimens per sample in December to January. Similarly, all shallow-water to intertidal sites along Transects A, B and C that were monitored monthly showed an increase from an average of 0-2 specimens per sample to around 13 specimens per sample in December to January. Brood eggs attached to crustacean specimens were observed in many samples collected during December to April. Two recruitment phases were recorded at site B9 during this period: an earlier phase in October 1986, and one in the December to January period. Sporadic occurrences of egg-bearing specimens also were noted in August and October each year at a number of sites. Hence, recruitment was not confined to the summer period.

Summer recruitment also was observed in *Corophium* sp populations at some sites (A1, A3, B9 and C15). How-

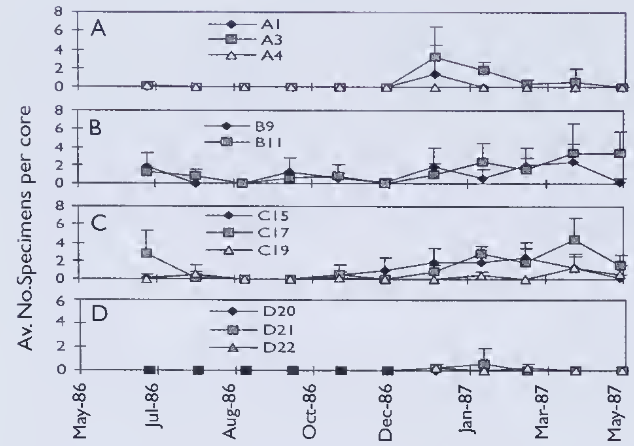

Figure 5. Monthly change in abundance of *Paranthura* sp at monitored sites along the four Transects (A-D) over the period May 1986 to May 1987 (mean abundance and standard deviation calculated from five sample replicates collected each month at each site).

ever, the majority of sites monitored monthly had consistently low numbers of specimens throughout the year. The shallow lower-estuarine reaches had the largest density changes over the summer where densities changed from a steady average of 0-2 specimens per sample up to 36 specimens per sample in January (Fig 4).

Paranthura sp was not commonly recorded in samples, hence it is difficult to establish reliable population patterns. Highest numbers were recorded from deep-water basin sites. It occurred along Transects B and C sporadically throughout the year, however peak numbers were recorded during January to March. The species was only recorded along Transects A and D during January to March (Fig 5).

The remaining species were not common enough to analyse for monthly to seasonal temporal patterns, although a number of trends can be discerned. *C. cf penantis* was more often recorded in summer months between December and February than at other times. *Melita* spp were recorded along Transect D and A in summer and generally only recorded along Transect D in winter.

Seasonal to annual population variation

Seasonal variation in composition and abundance of populations occurred along all transects over the five-year sampling period. Differences between winter and summer samples are illustrated by comparing winter 1986 and summer 1986/87 data for *Tanais* sp nov, *Corophium* sp and *Paranthura* sp (Fig 6). Four distinct seasonal trends were observed at different sites within the estuary. An increase in density of all three species was observed at sites B9 and C15. An increase in density of only one species was observed at sites A1, A3, D21 and D22, whereas no changes in density were observed at sites A4 and C19 and a decrease in density of species was observed at sites B11 and C17. Individual species patterns are described for each transect below.

Transect A Samples along Transect A showed a marked change in numbers and a change in proportions of the three species *Tanais* sp nov, *Corophium* sp and *Paranthura* sp at sites A1 and A3, but no change in numbers at site A4. Sites

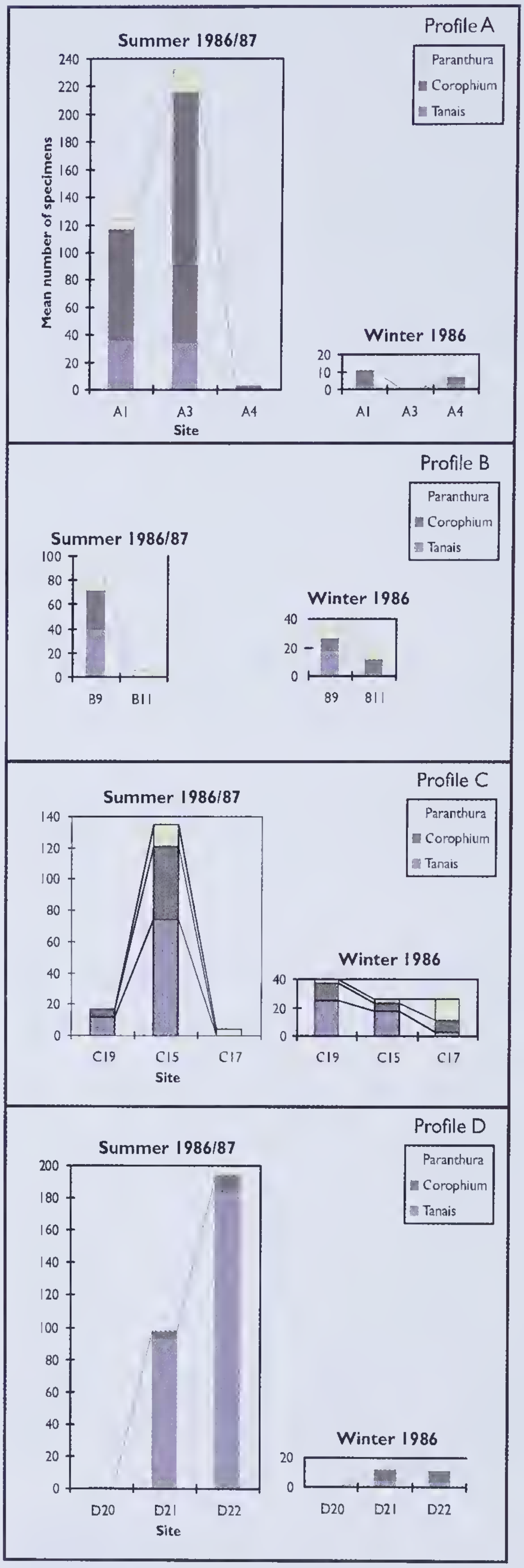

Figure 6. Summer and winter sample compositions for 1986/87 at monitored sites along the four east-west Transects (A-D). Summer compositions are based on total species counts from December 1986 and January 1987. Winter compositions are based on total species counts from June 1986 and July 1986.

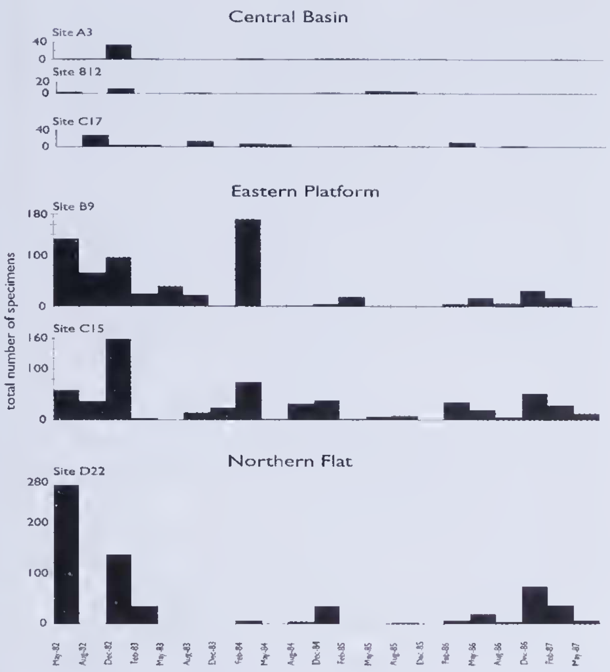

Figure 7. Long term annual changes in density of *Tanais* sp nov from seasonal data collected between May 1982 and May 1987. Total species counts from five replicate samples are given for each sampling occasion at each site. Sites are chosen to show population trends along the length of the estuary for deep-water and shallow-water regions.

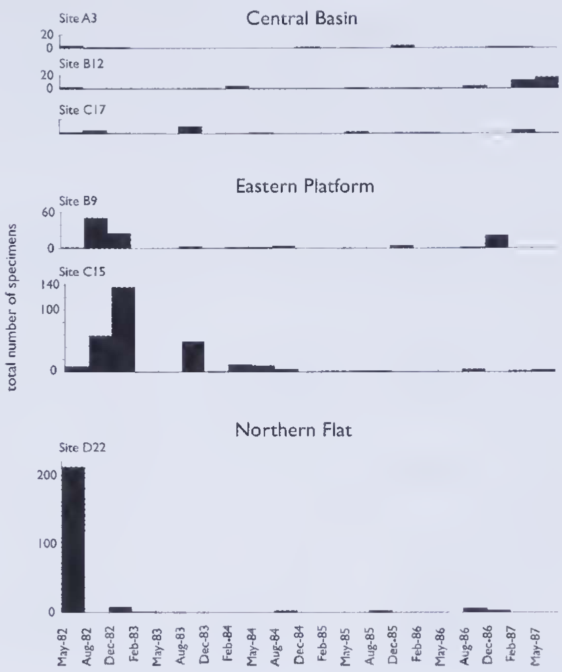

Figure 8. Long term annual changes in density of *Corophium* sp from seasonal data collected between May 1982 and May 1987. Total species counts from five replicate samples are given for each sampling occasion at each site. Sites are chosen to show population trends along the length of the estuary for deep-water and shallow-water regions.

A1 and A3 showed two orders of magnitude increase in density of *Corophium* sp, compared with a one order of magnitude increase in density of *Tanais* sp nov. *Paranthura* sp was only recorded in summer.

Transect B Sites B9 and B11 showed completely different seasonal trends. In winter, composition and abundance were similar between sites, however, numbers of all three species (*Tanais* sp nov, *Corophium* sp and *Paranthura* sp) doubled at site B9 in summer, whereas all specimen numbers decreased at site B11 (except for *Paranthura* sp).

Transect C Sites along Transect C showed similar trends for these species to those already described for Transect B: site C17 showed the same trends as site B11, site C15 was similar to site B9 and samples from site C19 showed no seasonal change in density.

Transect D Sites D21 and D22 showed two orders of magnitude increase in density of *Tanais* sp nov, whereas the density of *Corophium* sp remained constant. Site D20 showed no significant density changes.

Annual and long-term trends also are best illustrated by individual species. Figs 7 and 8 respectively show the total numbers of specimens of *Tanais* sp nov and *Corophium* sp at six selected sites over the five-year sampling period. These sites represent shallow-water sand and mud, and deep-water mud habitats within the estuary. Population peaks at sites A3, B12 and C17 are compared with salinity, temperature and oxygen saturation records collated by Wurm & Semeniuk (2001).

Tanais sp nov recruited mainly in December to February. Specimen numbers peaked markedly at sites A3, B9, C15 and D22 in December 1982 and at sites B9 and C15 in February 1984. These represent maxima within the five-year period of sampling. The major recruitment peak in summer of 1984 followed a polyhaline period at sites A3, B11 and C17 (which most probably affected the whole estuary in the winter of 1983). Recruitment peaks at site C17 also post-dated polyhaline periods. Peaks of lower magnitude occurred over the summer at sites B9, C15 and D22. Total numbers appeared to decline at most sites over the period 1984 to 1987, despite recurrent recruitment (Fig 9).

Corophium sp recruited mainly in the period August to December, but sometimes also in the period February to May. Specimen numbers peaked at sites B9, C15 and D22 between May and December 1982. The next highest peaks in populations at these sites occurred in August to December 1986. Total specimen numbers, however, declined dramatically between these recruitment periods. Peaks of lower magnitude occurred in August 1983, February 1984, August to December 1985 and 1986 at some of these sites. Recruitment was seasonal at some sites and intermittent at others. Peaks in population densities at sites A3, B12 or C17 do not correlate with seasonal patterns observed for salinity, temperature or oxygen.

Habitat associations

Wurm & Semeniuk (2000) recognised at least twenty-one habitat types within the Leschenault Inlet estuary. Fourteen of these habitat types were sampled regularly on benthic surveys of the estuary. Species abundance with respect to these habitats indicates some possible habitat associations (Table 2).

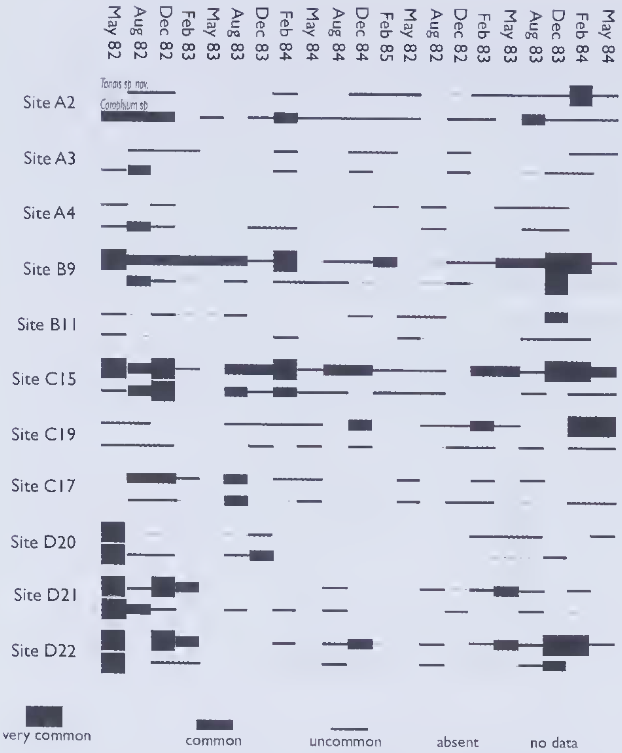

Figure 9. Long term changes in species occurrence at all 11 monthly monitored sites over the five-year period, May 1982 to May 1987. Abundance is rated as very common to rare based on the number of specimens recorded at each site.

While *Tanais* sp nov was an ubiquitous species occurring in all salinity fields, and nearly all habitats, it was distinctly less common at sites in the lower-estuarine field. Although there was no indication of salinity or substrate preference, the species appeared to prefer the higher temperatures or higher levels of oxygen found in shallower waters. Distribution information from other estuaries would be required to establish whether this species is a euryhaline marine or true estuarine species.

Corophium sp inhabited sandy habitats in mid to lower estuarine fields. Since it is also recorded from many other south-western Australian estuaries (Hodgkin & Clark 1987-1990; WA Museum of Natural Science crustacean database) this suggests it is a euryhaline opportunist or a true estuarine species.

Paranthura sp inhabited muddy sand to mud habitats in the mid to lower-estuarine fields. It is likely a euryhaline marine species, but distribution information from other areas would be required to confirm this conclusion.

Caprellid shrimps were recorded from most deltaic, lower and mid-estuarine sites within the Leschenault Inlet estuary, with the exception of sites in the most northern parts of the estuary. The shrimps were most common at vegetated muddy sand and mud basinal sites in the lower to mid-estuarine salinity field, generally at sites where salinities were close to normal marine conditions. A restricted distribution pattern within the Leschenault Inlet estuary is typical of stenohaline marine species with low tolerance for hyperhaline or polyhaline salinities. This species has both marine and estuarine records from Western Australia (WA Museum of Natural Science crustacean database).

Melita spp were restricted to intertidal and nearshore platform margin sites on the Collie river delta and northern intertidal flat. Both areas had variable salinity, including mesohaline periods. *Melita* spp within Leschenault Inlet estuary may have been associated with freshwater mixing zones along the estuarine margin and deltaic areas, since they were not recorded from all shallow-water nearshore sites. Both *Melita* spp were originally described from south-western Australian estuaries (Barnard 1972) and frequent records of *Melita* sp occur for many south-western Australian estuaries (Hodgkin & Clark 1987-1990), hence both are probably true estuarine species or euryhaline opportunists.

Small crabs were recorded from the Collie River Delta and central basin sites only. These genera were associated with lower-estuarine basinal sands and sandy muds with close to normal marine salinities. The numerous marine records of these small crab species from Western Australia suggest that they are stenohaline marine species (WA Museum of Natural Science crustacean database).

Some differences in the abundance of species occurred between sites representing the same habitat which suggest factors other than substrate and salinity play a role in determining species distributions (Table 2). *Tanais* sp nov was very common at lower-estuarine platform muddy sand site B9, but uncommon at sites A4, B10 and B13; very common at mid-estuarine muddy sand site C15, but not at site C16; common at deltaic intertidal sand site A1 and upper-estuarine intertidal mud site D22, but not at deltaic intertidal sand sites A6, A7 or upper-estuarine intertidal mud site D21. Environmental factors other than salinity, temperature and substrate may affect densities (*e.g.* oxygen saturation, depth or wave energy) and determine the shallow-water preference of *Tanais* sp nov. Alternatively, food source may be a factor.

Corophium sp, *Melita* spp and *Paranthura* sp showed only minor differences in abundance between sites representing the same habitat: *Corophium* sp and *Melita* spp were common at site B9, but not at A4, B10 or B13. This suggests site B9 may have environmental attributes which separate it from other lower-estuarine platform muddy sand sites *e.g.* the combination of shallow depth and nearshore wave energy may generate a different oxygen environment. It also has a higher seagrass biomass than most other sites along Transect B.

Most crustacean species present in the estuary may be regarded as euryhaline marine species or euryhaline opportunists, since the salinity range within the estuary is from 15-60 ‰. Some stenohaline marine species also are present, but do not occur in the polyhaline regions of the estuary. Freshwater species were not recorded because oligohaline to limnetic regions of the estuary only occur along the Preston and Collie river channels and were not sampled in this study.

Discussion

Estuarine environments typically have variable chemical and physical environmental conditions. Fauna assemblages reflect environmental heterogeneity in an instant in time along a coenocline, and through time at a given

Table 2. Abundance of crustacean species with respect to the habitat framework of Wurm & Semeniuk (2000)

Habitat	**Site**	*Tanais* sp nov	*Corophium* sp	*Paranthura* sp	*Melita zeylandica kauerti*	*Caprella cf penantis*
deltaic region intertidal sand salinity: mesohaline in winter; euhaline in summer	A1	*	**	**	*	-
	A6	*	**		-	
	A7	*	*		*	
deltaic region sand salinity: mesohaline in winter; euhaline in summer	A2	***	***	**	-	-
lower estuarine platform intertidal muddy sand salinity: euhaline	A5	*	***	-	*	*
lower estuarine platform muddy sand salinity: euhaline	A4	*	*	*	*	*
	B9	***	***	**	*	**
	B10	***	*	*	*	*
	B13	**	*	*	-	*
lower estuarine platform sand salinity: euhaline	B8	***	*	*	*	*
lower estuarine platform sandy mud salinity: euhaline	B14	*	-	**	-	-
lower estuarine basin sandy mud salinity: euhaline	A3	***	***	**	-	**
lower estuarine basin mud salinity: euhaline	B11	**	*	***	-	*
	B12	*	*			*
mid-estuarine platform intertidal sand salinity: fluctuating euhaline	C19	***	*	*	-	-
mid-estuarine platform sandy mud salinity: fluctuating euhaline	C18	***	-	*	-	*
mid-estuarine platform muddy sand salinity: fluctuating euhaline	C15	***	***	**	*	*
	C16	***	*	*	*	-
mid-estuarine basin mud salinity: euhaline	C17	***	*	**	-	**
upper estuarine intertidal sandy mud salinity: polyhaline in winter; hyperhaline in summer	D20	*	*	-	*	-
upper estuarine intertidal mud salinity: polyhaline in winter; hyperhaline in summer	D21	***	*	*	*	-
	D22	***	**	*	*	-

*** very common, ** common, * uncommon, - absent.

site due to fluctuating physical and chemical environmental conditions. A range of environmental factors, and especially salinity, appear to be first-order factors in determining species presence/absence at sites within this estuary. However, species distributions and densities exhibit recurrent temporal variation on seasonal to annual scales, probably caused by seasonal environmental changes and the intrinsic population dynamics of individual species. In addition, there is feedback between fluctuating environmental conditions and population dynamics because recruitment magnitude, juvenile and adult dispersal are all linked to favourable environmental conditions. Biological controls also could influence distribution patterns through species competition and predation. Temporal variation on decadal and longer time scales is likely linked to more dramatic shifts in environmental setting, such as nutrient enrichment, rather than to population response to fluctuating environmental conditions.

Without details on population size classes, reproduction, recruitment strategies, and information on a host of environmental factors, it is difficult to uncouple the biological from environmental processes that cause temporal variation in distribution and population density at a given site. Hence this discussion will first focus on net distribution patterns and then on changes to distribution and density of species on different time scales.

Faunal composition within this estuary does not reflect the typical lower to upper-estuarine faunal changes from marine to freshwater species found in most other estuaries (Day 1981; Kennish 1990). A longitudinal section across the Leschenault Inlet estuary shows a gradation in species between Transects A to D, in which the fauna components shift from euryhaline marine and stenohaline marine species to mainly euryhaline marine to mixed euryhaline species. However, this north to south pattern is disrupted at Transect A, which had euryhaline marine, estuarine opportunists and stenohaline marine components. There may even be a gradation in faunal composition, east to west, from river delta to Inlet, along Transect A. These unusual faunal patterns are attributed to the north-south oriented, elongated basin geometry and to the fact that the position of rivers in the Leschenault Inlet estuarine system generate atypical mid-estuarine and upper estuarine reaches. The mid-estuarine region does not have the classical polyhaline range in salinity and hence does not have the characteristic true estuarine components. The species composition in the "upper reaches" of this estuary (Transect D) is also highly uncharacteristic because it contains no oligohaline species. Species composition of the northern flat, in fact, is more analogous to coastal lagoon assemblages because this region experiences a hyperhaline period. Oligohaline species were found in the upper sections of rivers entering this estuary (Deeley, School of Environmental Science, Murdoch University, *pers comm.*), hence the true upper-estuarine salinity field of Kennish (1990) is located along the river channels adjacent to the lower-estuarine field. Thus, basin and river geometry accounts for the low number of stenohaline marine species and the absence of freshwater species recorded in the estuary proper, which contributes to a low overall species diversity.

Diversity patterns within the estuary reflect the complexity of environmental conditions within different estuarine fields. For instance, the highest diversity of small benthic crustaceans recorded along Transect A reflects the complexity of the juxtaposition of head and mouth of the estuary. Lowest diversity was recorded in the mid-estuarine field. Hence, the diversity pattern of the Leschenault Inlet estuary also differs from the typical estuarine pattern described by Kennish (1990) in which maximum diversity occurs in the mid-estuarine salinity field.

The distributions of the most common species of small benthic crustaceans were mainly widespread, but indicated some habitat associations. Tanaids were most abundant in well-oxygenated shallow areas of the northern flat, eastern and some western platform and deltaic sites even though habitats in these regions range from upper-estuarine intertidal mud to deltaic sands. *Corophium* sp was most common in deltaic to lower-estuarine platform sands, with the highest numbers recorded from the Collie Delta area; whereas *Paranthura* sp was most abundant in the mid to lower-estuarine muddy sand and mud habitats.

The common species from the melange of species within the various sites can be used to define four assemblage types within the estuary based on differences in the relative abundance of species. The deltaic region was characterised by high numbers of *Corophium* sp, with less common occurrences of other species including *Tanais* sp nov and *Melita* spp (the *Corophium-Tanais-Melita* assemblage). The mid to lower-estuarine regions had different shallow-water and deep-water assemblages; *Corophium* sp and *Tanais* sp nov dominated the shallow-water sites (the *Corophium-Tanais* assemblage), whereas *Paranthura* sp and *C. cf penantis* were found mainly in the deeper muddy sites (the *Paranthura-Tanais-Caprella* assemblage). Small crabs were found only in the lower-estuarine field at sites with close to normal marine salinities, hence the *Corophium-Tanais-Halicarcinus* assemblage only occurred at sites A3 and A4. The northern part of the estuary, the upper-estuarine field, was characterised by assemblages dominated by *Tanais* sp nov, with less common occurrences of *Melita* spp (the *Tanais-Melita* assemblage). Thus, assemblages could be distinguished from the following estuarine field and habitats; deltaic, lower-estuarine, near-shore lower to mid-estuarine, basin lower to mid-estuarine, and upper-estuarine. These assemblages appear to have been stable on seasonal to annual time scales.

Distribution of individual species based on presence/absence shows that most species are sensitive to at least one environmental variable. Those species found ubiquitously throughout the estuary showed density variation with respect to salinity and substrate, whereas those species that had restricted distribution showed correlation with salinity and vegetation. For example, salinity appeared to restrict the distributions of *Paranthura* sp, *Melita* spp, *C. cf penantis*, *H. ovatus* and other small crabs. In addition, the distribution of *C. cf penantis* was associated with the presence of vegetation within the mid to lower-estuarine salinity fields. This reflects habitat preference, but may also reflect some sampling bias since these mobile epiphytic crustaceans were more easily collected and trapped along with vegetation. The sample frequencies of *Corophium* sp and *Paranthura* sp show some correlation with substrate type within their distributions: *Corophium* sp had highest densities in sandy substrates whereas *Paranthura* sp appeared to prefer muddy substrates. Hence, a combination of substrate and salinity determined distributions of these two species within the estuary. The widespread shallow-water distribution of *Tanais* indicates that other important environmental factors, such as depth, oxygen saturation of the sediment, temperature or food source also played a role. Hence, distributions of the species were not always correlated to habitats defined on the physico-chemical and substrate criteria of Wurm & Semeniuk (2000). It is important to note that some environmental factors such as temperature and salinity varied on seasonal to annual cycles and hence would have affected distributions on these temporal scales, whereas other factors such as substrate are fixed constraints on distributions.

Seasonal changes in salinity and possibly other environmental shifts (such as oxygen and temperature) may contribute to transient changes in species distributions through their affect on adult migration and juvenile dispersal. Seasonal migration of adults probably accounts for changes in numbers of *C. cf penantis* and *Melita* spp at a number of sites. These species showed different summer and winter distribution patterns most likely linked to salinity changes, since temperature changes were fairly consistent for sites of similar depth throughout the estuary. For example, *Melita* spp were commonly recorded in the northern transect sites in winter and were less common in summer when the salinity regime shifted from meso

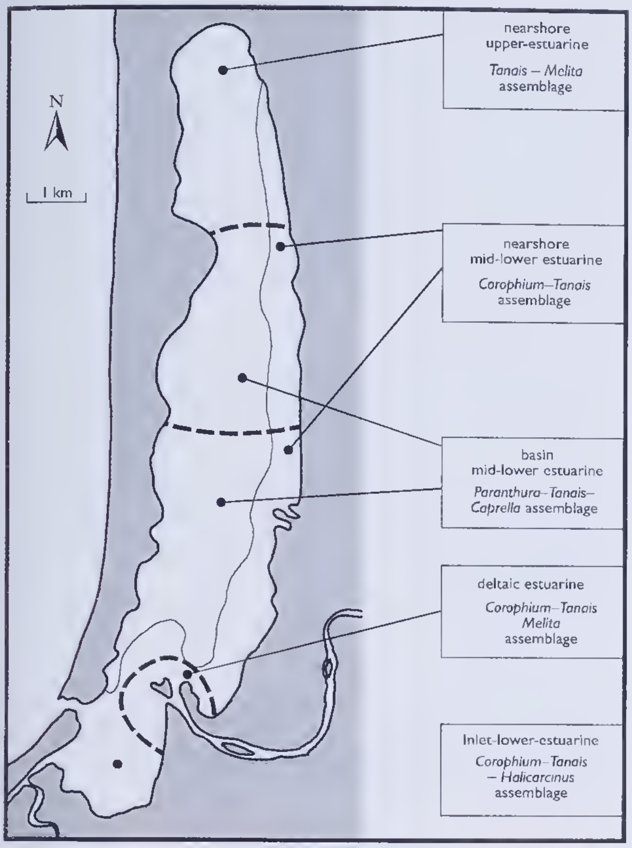

Figure 10. Distribution of small benthic crustacean assemblages. Four assemblages determined by salinity range and substrate types are defined for the Leschenault Inlet estuary; a deltaic estuarine assemblage, a basinal mid to lower-estuarine assemblage, a nearshore mid to lower-estuarine asemblage and a nearshore upper-estuarine assemblage.

to hyperhaline. In summer, *Melita* spp also were recorded from the Collie Delta region and a number of other shallow-water sites in the mid-estuarine reach.

Summer and winter distributions of species also varied seasonally due to juvenile dispersal. Extensive and widespread juvenile dispersal generally resulted in a given species extending beyond the distribution boundaries of the adult organism. For example, the more widespread summer distribution of *Paranthura* sp may have reflected juvenile dispersal. Juveniles probably disperse beyond the regions in which they can survive to maturity.

Temporal changes in population density at a given site were conspicuous, often involving changes in abundance of several orders of magnitude. Temporal changes in density could be discerned on monthly to seasonal scales (those linked to population dynamics) and also on annual to decadal changes (those linked to population adjustments to major shifts in environmental conditions).

Monthly and seasonal changes in density at a given site were probably linked mostly to recruitment. Summer recruitment peaks were typical for most species. Populations of *Tanais* sp nov, *Corophium* sp and *Paranthura* sp all peaked in density between December and February. Less common species were not recorded frequently enough to establish abundance changes through time.

The abundance data indicate that both *Tanais* sp nov and *Corophium* sp recruited preferentially in shallow to intertidal sites, since the greatest increase in density occurred at these sites. Spring to summer increase in density of these species at deeper water sites may be attributed either to a later, lower magnitude recruitment, or to adult dispersal due to local intra-species or inter-species competition. There was no evidence of juvenile dispersion from shallow sites to deeper water sites along the same transects. *Paranthura* sp recruited preferentially in deeper water at sites with close to normal marine salinities.

Monthly data showed that recruitment magnitude and timing varied on seasonal to annual scales. Annual recruitment of individual species did not always occur simultaneously at all sites throughout the estuary (Fig 9). Inhomogeneous recruitment resulted in different seasonal and annual trends for each species at each site. For example, differences in the magnitude and timing of recruitment occurred between shallow- and deep-water populations of both *Tanais* sp nov and *Corophium* sp. Magnitude and timing of recruitment may have been influenced by local temperature, salinity change or to food supply. Clearly, from the perspective of specimen numbers and recruitment patterns, central basin and western platform appear to have been the preferred shallow-water habitat for both species.

Annual to longer term abundance patterns over the period 1982-1987 suggest that regular, if not annual, recruitment occurred in summer for most species over this period. Both *Tanais* sp nov and *Corophium* sp showed seasonal recruitment over the five-year period at least at one site. *Tanais* sp nov appears to be a resident species because it has an annual periodic recruitment pattern at most shallow-water sites and some deep-water sites. Recruitment during the December to February period was variable in magnitude, probably dependent on year to year environmental conditions. Major peaks recorded after polyhaline periods may represent population response after severe winter mortality. *Corophium* sp had a regular, but not annual recruitment pattern only at some shallow-water sites. The aperiodic recruitment of *Corophium* sp suggests that this species was greatly affected by the fluctuating environmental conditions within the estuary. Both species appeared to behave independently, since recruitment was not necessarily coincident with other species, and there was no indication of an inverse recruitment relationship between species over the five-year sampling period.

Over the five-year period of sampling there was an overall decline in numbers of both the dominant species. *Tanais* sp nov numbers decreased at sites B9 and C15. These declines may represent a shift in environmental conditions within the estuary *e.g.* an increase in nutrients within the estuary system. Similarly, *Corophium* sp numbers at site C15 declined over the same period. The decline in numbers of *Corophium* sp is even more obvious when populations at other sites are considered: this species has only been recorded commonly from site B9 since 1982, and only sites A2 and C15 show regular recruitment patterns (Fig 9). The unexpected high numbers recorded at site B9 in December 1986 and at site B12 in May 1987 is evidence for aperiodic recruitment. The decline in population of this species is difficult to interpret: it may represent response to adverse environmental change or it may reflect the population dynamics of an estuarine opportunist (Kennish 1990). Comparison of 1982-1987 environmental data with the current status of the estuary would establish whether these declines are linked to environmental change or to long term population dynamics.

The range of new species recorded in 1997 that had not been previously recorded in the estuary is another indication of compositional change in the estuary. Comparison of crustacean records with Chalmer & Scott (1984) indicate that the species assemblage present in 1974 was similar in composition and abundance to 1982, whereas the samples from 1997, twenty three and fifteen years later, respectively, were significantly different. The record of species associated with algae, especially *Amphitoe* indicate change in aquatic vegetation density and distribution within the estuary. The increase in algae at sites A4, C15 and D22 in 1997 compared with 1982-1987, is most likely the result of nutrient enrichment.

There is evidence for a number of environmental changes in physical, chemical and ecological conditions over the last decade. For example, Lukatelich (1989) documented changes in seagrass density over the period 1984-1988, and Ruiz-Avila & Klemm (1993) reported large variability in water chemistry between years. Either of these factors could generate long-term changes in fauna characteristics.

One possible underlying cause of environmental change is increased nutrient enrichment of the estuary. The estuary was first reported as being mildly "eutrophic" in 1991 (Hill *et al.* 1991). Nutrient enrichment would result in a change in chemical conditions and in the composition of primary producers, *e.g.* an increase, then a decrease in seagrass density at most sites, an increase in seaweed at most sites, and a decrease in available oxygen in water and sediment columns. Hence, population dynamics would be complicated by ever changing environmental stress.

The change in species composition and decline in abundance of both dominant species is most consistent with an environmental shift over time, rather than with patterns arising from a large variability in local conditions between years. Such a shift appears to preclude favourable recruitment resulting in low density, "maintenance" populations. Such environmental change will result in an ongoing change in population composition and structure of benthic crustaceans within the Leschenault Inlet estuary over the long term, until environmental conditions stabilise.

Only four out of the 21 species of small benthic crustaceans recorded for the Leschenault Inlet estuary in this study were previously recorded by other authors (it is possible overlap is higher because many small benthic crustaceans remain unidentified from previous work). All small benthic species recorded by other authors were recorded in this study. Differences in total species number partly reflect differences in rigor of sampling and sampling methods, but also temporal changes in species composition of this estuary.

A subset of the total small benthic crustacean species list for the Leschenault Inlet estuary has already been recorded for other estuaries in south-western Australia, hence there are faunal similarities with other estuaries. However, regional comparisons cannot be discussed in detail, since this study indicates that seasonal and annual changes in estuarine crustacean fauna are marked. Thus, single surveys, as have been conducted to date, may not be representative of diversity or species composition of benthic crustacean communities in estuaries, and a more rigorous study of other estuaries would be required to establish valid regional patterns. It also means comparative studies must take into account the marked annual to decadal changes in species linked to physico-chemical environmental changes in estuaries over time.

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